SECTION 1
INTRODUCTION

1.1 BACKGROUND

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy. NTIA's responsibilities include establishing policies concerning spectrum assignments, allocation and use, and providing various departments and agencies with guidance to ensure that their conduct of telecommunication activities is consistent with these policies.[8] Accordingly, NTIA conducts studies and makes recommendations regarding telecommunications policies and presents Executive Branch views on telecommunications matters to the Congress, the Federal Communications Commission (FCC), and the public.

NTIA is responsible for managing the Federal Government's use of the radio frequency spectrum. The FCC is responsible for managing the spectrum used by the private sector, and state and local governments. In support of its responsibilities, the NTIA has undertaken numerous spectrum-related studies to assess spectrum utilization, studied the feasibility of reallocating spectrum used by the government or relocating government systems, identified existing or potential compatibility problems between systems, provided recommendations for resolving any compatibility conflicts, and recommend changes to promote efficient and effective use of the radio spectrum and to improve spectrum management procedures.

Recent advances in microcircuit and other technologies have resulted in the development of pulsed radar and communications systems with very narrow pulse widths and, consequently, very wide bandwidths. These ultrawideband (UWB) systems have instantaneous bandwidths of at least 25 percent of the center frequency of the device and thereby cannot conform the U.S. frequency allocation table and the associated Federal regulations.[9] UWB systems have shown promise in performing a number of useful telecommunication functions that make them very appealing for both commercial and government applications. These systems have very wide information bandwidths, are capable of accurately locating nearby objects, and can use processing technology with UWB pulses to "see through objects" and communicate using multiple propagation paths. However, the bandwidths of UWB devices are so wide that, although their output powers, in many cases, are low enough to be authorized under the unlicensed device regulations

[8] National Telecommunications and Information Administration, U.S. Dept. of Commerce, Manual of Regulations and Procedures for Federal Radio Frequency Management, at Chapter 2 (Jan. 2000).

[9] There are several ways of generating very wide signals including spread spectrum and frequency hopping and chirping techniques. The UWB signals for the devices of concern in this study are generated by direct current impulse responses fired into a tuned circuit. This generates a burst of energy of ideally one positive going cycle shaped by the tuned circuit to a specific portion of the spectrum.

of the NTIA and the FCC, some of the systems emit signals in frequency bands in which such transmissions are not permitted because of the potential harmful effects on critical radiocommunication services.

The FCC, in coordination with NTIA, developed rules for unlicensed devices (conventional electronic devices with narrow bandwidths) that did not address the then unknown UWB devices (47 Code of Federal Regulations (CFR) §§ 15.1 et seq.). To obtain information on UWB devices and decide whether accommodating them as unlicensed devices under Part 15, the FCC issued a *Notice of Inquiry (NOI).*[10] Also, after an initial investigation by NTIA and the FCC, the FCC, in coordination with NTIA, granted limited waivers authorizing the marketing of UWB devices manufactured by three companies. Subsequent to the NOI, the FCC issued a *Notice of Proposed Rule Making (NPRM),* on the revision of Part 15 rules regarding UWB transmission systems.[11]

This report addresses the emissions from UWB devices that occur primarily in the restricted frequency bands,[12] and the possibility of degradation to the performance of critical Federal telecommunication systems except for the Global Positioning System (GPS), which is analyzed in several separate studies. Before NTIA can accept the operation of UWB devices in the restricted frequency bands used by critical Federal radio systems, it must assess the potential impact of UWB devices on these systems, as well as develop solutions to any problems identified. A subsequent NTIA report will address policies and rules pertaining to UWB devices.

UWB operation on an unlicensed basis has been proposed to operate under 47 CFR Part 15 which sets out the regulations under which an intentional, unintentional, or incidental radiator may be operated without an individual license. Part 15 stipulates that unlicenced devices are subject to the condition that no harmful interference is caused to licenced services and that harmful interference to unlicenced devices must be accepted. It is recognized and stated in Part 15.5(c) that "the limits specified in this part will not prevent harmful interference in all circumstances."

1.2 OBJECTIVE

The objective of this report was to provide an assessment of the compatibility between UWB devices and selected Federal systems.

[10] *See Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems,* ET Docket No. 98-153, Notice of Inquiry, 63 Fed. Reg. 50184 (Sept. 21, 1998) [hereinafter UWB NOI].

[11] *See* UWB NPRM, *supra* note 2.

[12] "Restricted bands" of operation are listed in 47 CFR §15.205. With certain exceptions, the only emissions radiated from unlicensed devices, that are allowed in these bands are spurious emissions. Spurious emissions per 47 CFR 2.1, are emissions "...which may be reduced without affecting the corresponding transmission of information."

1.3 APPROACH

In order to accomplish the above objective, NTIA developed, first, a Master Plan to provide a comprehensive approach for obtaining the information required to perform a detailed assessment, and then, a more detailed measurement plan to measure the characteristics of UWB devices and provide the basis for an analytical model used to assess the impact. These plans were provided directly to the Federal agencies and to the public via the Federal Register for comment.[13] The FCC's NPRM on Revision of Part 15 Rules Regarding UWB Transmission Systems was reviewed to make sure that NTIA's effort would address issues for which the FCC sought guidance. NTIA, thus, undertook a comprehensive program consisting of measurements, analytical analysis, and simulations to characterize UWB transmissions and their potential to interact with Federal telecommunication systems. The program included:

A) Establishing a UWB measurement plan to:

1) Develop measurement procedures that use commercial off-the-shelf measurement equipment to accurately portray UWB emission characteristics;
2) Observe the effects of UWB signals in the intermediate frequency (IF) sections of selected receivers, and determine the susceptibility of conventional radio receivers to UWB emissions;
3) Provide a basis for development of a one-on-one interference analysis procedure to determine maximum permitted equivalent isotropic radiated power (EIRP) level or minimum distance separation of UWB devices to ensure compatibility;
4) Perform a limited set of measurements to validate the one-on-one interference analysis (above) between UWB signals and selected Federal radio receivers, particularly radio navigation and safety-of-life systems; and
5) Assess the potential aggregate or cumulative effects of multiple UWB emissions through measurements.

B) Conducting analytical analysis and simulations to:

1) Describe the temporal and spectral characteristics of UWB signals;
2) Characterize an aggregate of UWB signals; and
3) Identify the time waveform and power transfer characteristics of UWB signals in receiver systems as a function of receiver IF bandwidths.

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[13] Ultra Wideband signals for Sensing and Communication: A Plan for Developing Measurement Methods, Characterizing the Signals and Estimating Their Effects on Existing Systems, August 25, 2000, (see NTIA homepage www.ntia.doc.gov/osmhome/uwbtestplan/), and Ultra-Wideband Signals for Sensing, and Communications: A Master Plan for Developing Measurement Methods, Characterizing the Signals and Estimating Their Effects on Existing Systems, ITS Ultra-Wideband Measurement Plan (Master Plan Task 1.2), August 25, 2000, (see NTIA homepage www.ntia.doc.gov/osmhome/uwbtestplan/). These are the final plans incorporating the comments of the Federal government and public sector.

Results of the measurements, analytical analysis and simulations are contained in an NTIA Report.[14]

C) Based on information obtained from "A" and "B" above, the following steps were taken:

1) An analysis procedure and an analytical model were developed to determine the maximum permitted EIRP level and the minimum distance separation which will ensure compatibility between UWB devices and other telecommunications systems. The analytical model was compared to measurements made on two Federal telecommunication systems.
2) An aggregate analytical model was developed to identify the potential cumulative effects of UWB devices.

D) The systems selected for the analysis were chosen primarily due to their crucial role in aviation safety, and with the exception of the Terminal Doppler Weather Radar (TDWR),[15] and maritime radionavigation radars operate in restricted frequency bands. The Federal radiocommunications systems that were chosen for the analysis are listed in TABLE 1-1 along with their allocation bands.

E) The technical characteristics of Federal telecommunication systems listed in TABLE 1-1 needed to conduct an electromagnetic compatibility (EMC) study were identified, and applied to the analytical models described in "C" above. Based on the results of applying the analytical models, maximum permitted EIRP levels and minimum distance separations which will ensure compatibility between UWB devices and other telecommunications systems were identified.

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[14] National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report, The Temporal and Spectral Characteristics of Ultrawideband Signals, Jan. 2001 [hereinafter ITS Report].

[15] Although the TDWR does not operate in a restricted frequency band, the system performs a critical mission of detecting micro bursts, wind shear, near airports to ensure safe landing of aircraft. Unlicensed device operation in this frequency band is still subject to the condition that no harmful interference be caused and that interference to the unlicensed device must be accepted 47 CFR Part 15.5(b). This also applies to maritime radionavigation radars in the 2900-3100 MHz frequency band.

TABLE 1-1
Systems Analyzed in the Single UWB Emitter Analyses

System	Receive Frequency (MHz)	Function
Distance Measuring Equipment (DME) Airborne Interrogator	960-1215	Provides civil and military aircraft pilots with distance from a specific ground beacon (transponder) for navigational purposes.
DME Ground Transponder	1025-1150	Ground transponder component which replies to interrogations from the DME airborne component.
Air Traffic Control Radio Beacon System (ATCRBS) Ground Interrogator	1090	Used in conjunction with the ASR and ARSR radars to provide air traffic controllers with location, altitude and identity of civil and military aircraft.
ATCRBS Airborne Transponder	1030	ATCRBS airborne transponder component of ATCRBS system which replies to the ground interrogator and provides altitude and aircraft identity information in the reply signal.
Air Route Surveillance Radar (ARSR-4)	1240-1400	Used by the Federal Aviation Administration (FAA) and Department of Defense (DoD) to monitor aircraft during enroute flight to distances of beyond 370 km (200 nm).
Search and Rescue Satellite Land User Terminal (SARSAT LUT)	1544-1545	Provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress.
Airport Surveillance Radar (ASR-9)	2700-2900	Monitors location of civil and military aircraft in and around airports to a range of 110 km.
Next Generation Weather Radar (NEXRAD)	2700-3000	Provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information.
Maritime Radionavigation Radar	2900-3100	Maritime radionavigation radars provide a safety service function that assists vessel commanders in safe navigation of waterways. The marine radar provides information on surface craft locations, obstructions, buoy markers, and navigation marks (shore-based racons, radar beacons) to assist in navigation and collision avoidance.
Fixed Satellite Service (FSS) Earth Stations	3700-4200	Used to receive downlink transmissions from geosynchronous satellites for a variety of applications, including voice, data, and video services for Federal agencies.
RF Altimeters	4200-4400	Provides pilots of civil and military aircraft and air traffic controllers with information on the height of an aircraft above ground level (AGL).
Microwave Landing System (MLS)	5030-5091	Used for precision approach and landing of aircraft.
TDWR*	5600-5650	Provides quantitative measurements of gust fronts, wind shear, micro bursts, and other weather hazards for improving the safety of operations at major airports.

* Note: The TDWR does not operate in the restricted frequency bands.

SECTION 2

DISCUSSION OF NPRM REGARDING UWB TRANSMISSION SYSTEMS

2.1 INTRODUCTION

The FCC NPRM discusses rules and regulations for UWB transmission systems that would be incorporated under 47 CFR Part 15.[16] This section discusses FCC proposed Part 15 Rules for emission limits as a basis for conducting an EMC analysis. NTIA has converted the Part 15 Limits, which are stated as field strengths measured at a specific distance, to the transmitting device's EIRP levels. Also, measurement procedures currently used by the FCC in assessing compliance with rules are identified since they are a key to establishing an EMC analysis procedure.

2.2 PROPOSED UWB DEVICE EMISSION LIMITS

2.2.1 Average and Quasi-Peak Power Limits

The FCC sought comments on the sufficiency of the existing Part 15 general emission limits to protect other users, especially radio operations within the restricted frequency bands from harmful interference or whether different limits should be applied to UWB systems.[17]

Section15.209 of the FCC's rules establishes general requirements for radiated emission limits for intentional radiators, which are reproduced below in TABLE 2-1. Conformance to the field strength limits is assessed using an International Special Committee for Radio Interference (CISPR) quasi-peak detector except for the frequency bands 9-90 kHz, 110-490 kHz and above 1000 MHz. In these three bands, an average detector is used.[18] Also, included in TABLE 2-1 is the measurement reference bandwidth and the EIRP calculated using the equation in note (b) of the table.

Regarding measurements using an average detector, the FCC's measurement procedure in an average logarithm detector process is not equivalent to an root-mean-square (RMS) detector process. Measurements have shown that the average logarithm is largely insensitive to energy contained in low-duty-cycle, high amplitude signals. This results in Part 15 measurement values that can be substantially lower

[16] *See* UWB NPRM, *supra* note 2, at ¶ 1.

[17] *Id.* at ¶ 34.

[18] The FCC measurement method calls for video filtering in which a 1 MHz bandwidth filter is used in conjunction with a video filter with a bandwidth not less than 10 Hz .

(10-15 dB) than the RMS power in a UWB signal.[19] Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, NTIA measurements and analysis indicates that the RMS detector function better quantifies the potential interference affects of UWB signals than the current average-logarithmic detector function used for Part 15 compliance.[20]

TABLE 2-1
Section 15.209 Radiated Emission Limits

Frequency (MHz)	Field Strength[a] (μV/m)	Measurement Distance (m)	Reference Measurement Bandwidth (kHz)	EIRP[b] (dBm)
0.009–0.015	2400/F(kHz)	300	0.30	11.8 $-20\log_{10}F$(kHz)
0.015–0.490	2400/F(kHz)	300	10	11.8 $-20\log_{10}F$(kHz)
0.490–1.705	24000/F(kHz)	30	10	12.3 $-20\log_{10}F$(kHz)
1.705–30.0	30	30	10	-45.7
30–88	100[c]	3	100	-55.3
88–216	150[c]	3	100	-51.7
216–960	200[c]	3	100	-49.2
960-1000	500	3	100	-41.3
above 1000	500	3	1000	-41.3

a) Below 1000 MHz, the field strength emission limits specified are based on measurements employing a CISPR quasi-peak detector, except for the frequency bands: 9-90 kHz, 110-490 kHz, and above 1000 MHz. Emission limits in these three frequency bands are based on measurements employing an average-logarithmic detector.

b) The field strength emission limits were converted to an EIRP level in dBm using the following equation.

$$\text{EIRP(dBm)} = E_o(\text{dB}\mu\text{V/m}) + 20\log_{10}D(\text{m}) - 104.8$$

c) Except for perimeter protection systems and biomedical telemetry systems, fundamental emissions from intentional radiators operating under Section 15.209 shall not be located in the frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz, or 470-806 MHz, except as specified in 15.231 & 15.241.

The FCC also seeks comments on proposals that emissions from UWB devices, other than ground penetrating radars and possibly through wall imaging systems, operating below approximately 2 GHz be at least 12 dB below the general emission limits of 47 CFR

19 *See* ITS Report, *supra* note 14, at §8.4 (Items 5, 6, and 7).

20 *Id.* at §6.4.6 and A.2.2.

Section 15.209. Comments are requested on whether additional attenuation below 2 GHz is possible or necessary and whether the proposed reduction in the emission levels should apply to all emissions below 2 GHz or only to emissions below 2 GHz that fall within the restricted frequency bands shown in 47 CFR Section 15.205. The FCC also seeks comments on any changes to the technical standards or operational parameters of UWB transmitters that could be employed to facilitate the operation of these products below 2 GHz.[21]

2.2.2 Peak Power Limits

Section15.35 of the FCC rules states that when average radiated emission measurements are specified in the regulations, the radio frequency emissions, measured using instrumentation with a peak detector function, can be no more than 20 dB above the maximum permitted average limit. The FCC has applied this 20 dB limit to the total peak power in the transmitted waveform. Thus, the peak power limit is measured in a bandwidth sufficient to capture the total peak power, and **not** measured in a 1 MHz reference bandwidth.

The FCC states in the NPRM that a limit on peak emissions is necessary to reduce the potential for UWB emitters to cause harmful interference to radio operations above 1 GHz.[22] Two methods of measurement to assess conformity are also presented for comment: 1) the peak level of the emission when measured over a bandwidth of 50 MHz which the FCC states is comparable to the widest victim receiver likely to be encountered; 2) the absolute peak output of the emission over its entire bandwidth.[23] For the peak signal strength measured over the 50 MHz bandwidth, the FCC seeks comments on proposals to apply a 20 dB limit above the maximum permitted average emission level.[24] For the absolute peak limit for the emission over its entire bandwidth, the FCC seeks comments on proposals that it be variable based on the amount of the -10 dB bandwidth of the UWB emission exceeds 50 MHz.[25] Appendix D of this report addresses peak power of UWB signals in a 50 MHz bandwidth.

2.3 SIGNAL GATING

The FCC's NPRM does not address gating of the UWB signal. Gating is the turning on and off of the UWB signal for some period of time. The gating percent is defined as the percent of the time the signal is on. For example, a UWB signal that has a 25 percent gated signal would have the signal on for 25 percent of the period and off for 75 percent

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21 *See* UWB NPRM, *supra* note 2, at ¶ 39.

22 *Id.* at ¶ 42.

23 *Id.*

24 *Id.* at ¶ 43.

25 *Id.*

of the period. NTIA conducted measurements on several UWB devices which implemented gating of the transmitted waveform. There are several questions concerning procedures for establishing emission limits for UWB devices implementing gating. For example, will the average (RMS) power be measured only when the signal is on, or will the average (RMS) power be measured over the entire period?

2.4 SUMMARY OF PROPOSED EMISSION LIMITS

Although the FCC states that the general emission limits for intentional radiators contained in 47 CFR § 15.209 appears to be appropriate for UWB operations, they sought comments on the sufficiency of the existing Part 15 general emission limits to protect other users, especially radio operations within the restricted frequency bands from harmful interference or whether different limits should be applied to UWB systems. Also, the FCC states that a limit on peak emissions is necessary to reduce the potential for UWB emitters to cause harmful interference to radio operations above 1 GHz; however, at this time no peak power limit or measurement procedure for UWB devices has been adopted. The FCC did not propose any change to the measurement reference bandwidths for average (RMS) power (see TABLE 2-1).

SECTION 3

ELECTROMAGNETIC COMPATIBILITY ANALYSIS PROCEDURE

3.1 INTRODUCTION

This section discusses the analysis procedures used to determine the maximum permitted EIRP level and minimum distance separation which will ensure compatibility between UWB devices and other telecommunications systems. A description of the EMC analytical model (which uses a commercially available spreadsheet) used to assess compatibility is provided. Also, the analysis results are compared with measured data taken on two telecommunication systems.

3.2 GENERAL EMC ANALYSIS APPROACH

Considering the FCC is seeking information on appropriate emission limits for UWB devices, the EMC analysis must be focused on determining the permitted EIRP of UWB devices which will ensure compatibility. In establishing a permitted EIRP level, it is necessary to establish a reference measurement bandwidth and a spectrum analyzer detector function. The measurement reference bandwidth is required to convert the UWB signal power level at the receiver input to the UWB signal power level at the victim receiver IF output. The identification of a detector function is also key to ensuring that the establishment of any standards will be based on a particular spectrum analyzer detector function.

Based on the UWB NPRM (see Section 2) and the NTIA measurements of UWB device characteristics, the following EMC analysis approach was taken.

1. The analysis was based on a spectrum analyzer RMS detector function for average power.[26] This average (RMS) level is **not** equivalent to the Part 15 log-average level. See ITS Report.[27]

2. The measurement reference bandwidth, B_{ref}, for establishing the EIRP limit was based on the information in TABLE 2-1 of Section 2 (e.g., for systems operating above 1000 MHz, the measurement reference bandwidth is 1 MHz).

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[26] Throughout this report average power is based on the Root-Mean-Square (RMS) voltage of the UWB signal. For clarity, average power will be written as average (RMS) power, and the EIRP average power spectral density will be expressed as EIRP dBm/MHz RMS.

[27] *See* ITS Report, *supra* note 14, at § 8.4 (Items 5, 6, and 7), and A.2.2.

3. A Bandwidth Correction Factor (BWCF) was developed to correct for the average and peak power level of the UWB signal at the victim receiver IF output. The BWCF was normalized to the average (RMS) power level in the measurement reference bandwidth, B_{ref}.

4. The analysis did not limit the peak to average (RMS) power ratio (e.g., 20 dB in a 50 MHz bandwidth) since a peak to average (RMS) power ratio limit for UWB devices has not been established. The FCC has proposed a peak power limit of 20 dB in a 50 MHz bandwidth.[28] Appendix D of this report address peak power of UWB signals in a 50 MHz bandwidth.

5. The analysis assumes that for gated transmissions the average (RMS) power was measured over one or more gated periods. That is, it was not averaged over only the period when the pulse train is on.

6. The required distance separation was based on an EIRP limit of UWB devices equal to -41.3 dBm/MHz (RMS). The systems that were studied operate above 1000 MHz. Therefore, the EIRP limit was based on the emission limit given in TABLE 2-1 of Section 2 for the frequency range above 1000 MHz.

3.3 ESTABLISHMENT OF UWB DEVICE EMISSION LIMITS

The maximum permitted EIRP level was determined using the following equation:

$$EIRP_{MAX} = + I_{MAX} - BWCF_{A/P} - G_R(\theta) + L_P + L_R + DCF + GF \qquad (3\text{-}1)$$

where:

$EIRP_{MAX}$ = the maximum permitted EIRP of the UWB device, in dBm/B_{ref} (RMS).

I_{MAX} = the maximum permissible average or peak interference level at the receiver input, in dBm.

$BWCF_{A/P}$ = the receiver BWCF to correct for the power of the UWB signal at the victim receiver IF bandwidth (B_{IF}) output relative to the Part 15 measurement reference bandwidth, B_{ref} (see TABLE 2-1, Section 2). The BWCF is normalized to the average (RMS) power level in a 1 MHz bandwidth, and provides a correction for the UWB signal average (RMS) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output, in dB.

[28] *See* UWB NPRM, *supra* note 2, at ¶ 42.

$G_R(\theta)$ = the victim receiver elevation pattern antenna gain in the direction of the UWB device, in dBi.

L_P = the propagation loss between transmitting and receiving antennas, in dB.

L_R = the insertion loss (loss between the receiver antenna and receiver input), in dB.

DCF = a detector correction factor (DCF) to correct for the type of detector used in the Part 15 measurement procedure, quasi-peak or average detector (see TABLE 2-1 Section 2, Note "a").

GF = a gating factor (GF) to correct for the increase in peak power when the UWB device transmissions are gated.

3.4 MAXIMUM PERMISSIBLE INTERFERENCE LEVEL

The initial step in determining the maximum permitted EIRP level and required minimum separation distance to ensure compatibility is to establish a maximum permissible interference level, I_{MAX}, which requires the identification of a protection criterion for each system. Generally the protection criteria are specified in terms of an average or peak interference-to-noise ratio (I/N) or signal/carrier-to-average or peak interference ratio (S/I or C/I). Appendix A contains the protection criteria for the radiocommunication systems considered in this study.

$$I_{MAX} = I/N + N, \text{ or} \tag{3-2}$$

$$I_{MAX} = S - S/I \tag{3-3}$$

where: I/N = the maximum permissible average or peak interference-to-noise ratio at the receiver IF output (detector input) necessary to maintain acceptable performance criteria, in dB.

N = the receiver inherent noise level at the receiver IF output referred to the receiver input, in dBm.

S/I = minimum signal-to-average or peak Interference ratio at the receiver IF output (detector input) necessary to maintain acceptable performance criteria, in dB. Sometimes a carrier-to-interference ratio (C/I) is used.

S = desired signal level at the receiver input, in dBm. Sometimes a carrier level (C) is used.

For a known receiver IF bandwidth and receiver noise figure (NF) or system noise temperature, the receiver inherent noise level is given by:

$$N = -114 \text{ dBm} + 10\log B_{IF}(\text{MHz}) + NF \quad (3\text{-}4a)$$

$$N = -144 \text{ dBm} + 10\log B_{IF}(\text{kHz}) + NF \quad (3\text{-}4b)$$

or

$$N = KT_sB_{IF} = -198.6 \text{ dBm}/^{o}\text{K/Hz} + 10\log T_s(^{o}\text{K}) + 10\log B_{IF}(\text{Hz}) \quad (3\text{-}4c)$$

where: B_{IF} = the receiver IF bandwidth (see equations for units)
NF = the receiver NF, in dB
K = Boltzmann's constant, 1.38×10^{-23}, in Watts/°K/Hz
T_s = the system noise temperature, in degrees Kelvin

3.5 BANDWIDTH CORRECTION FACTOR (BWCF)

The following is a discussion of the procedure for calculating the BWCF for various UWB modulation types and ranges of victim receiver IF bandwidths (B_{IF}) relative to the Part 15 measurement reference bandwidth (B_{ref}) given in TABLE 2-1 for various frequency bands. The equations are based on measurements and simulations contained in the ITS report.[29] The BWCF equations are normalized to the average (RMS) power level in a 1 MHz bandwidth, and provide a correction for the UWB signal average (RMS) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output, in dB. The equations do not include any additional peak power factor for gated UWB signals. Also, the equations assume that the UWB device emissions are uniform across the receiver IF bandwidth. That is, the receiver IF bandwidth is less than 1/T, where T is the pulse width of the UWB device.

Part 15 limits above 1000 MHz are specified as an average power limit of 500 µv/m at 3 meters (Part 15.209) which equates to -41.3 dBm/MHz EIRP.[30] The total peak power (measured in a bandwidth to capture the total peak power) is limited to 20 dB above the maximum permitted average power (Part 15.35b). To assess the compatibility of UWB systems with other telecommunication systems, both average and peak power levels at the receiver IF output (detector input) of the telecommunication systems is required. Therefore, a BWCF must be determined to correct for the difference in power as measured in the Part 15.209 reference bandwidth (B_{ref}) and the receiver IF bandwidth (B_{IF}) of the victim radiocommunication system. Since the victim receiver performance degradation may be a function of the UWB signal average power level or peak power level at the receiver IF output, a correction factor for the UWB signal average (RMS) power level ($BWCF_A$) and peak power level ($BWCF_P$) at the victim receiver IF output are provided.

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[29] *See* ITS Report, *supra* note 14, at Section 8, Appendix B, and Appendix D.

[30] The FCC average power level is a log-average power level based on their measurement procedure. The BWCF is normalized to the average (RMS) power level.

The UWB signal time waveform and power level at the victim receiver IF output is a function of the type of modulation used in the UWB device and the victim receiver's IF bandwidth. The major UWB modulation parameters affecting the UWB time waveform and power level at the receiver IF output are the pulse repetition frequency (PRF), the pulse width (T), and the use of time dithering and/or gating of the UWB device.

Dithering, as referred to in this report, is the intentional variation in the interpulse period. One method of dithering a signal is to use the random amplitude of a white-noise source which results in a smearing of the spectral lines, which gives a more noise-like spectra. Another method is to control the pulse-to-pulse timing using a pseudo-random code. However, the code length has an influence on whether the signal exhibits characteristics closer to a random noise-like signal.

Note: The limiting conditions associated with each of the Equations 3-5 through 3-14, must be met to ensure applicability of the equations.

3.5.1 UWB Non-Dithered Pulse Trains

UWB systems not using time dithering will produce spectral lines in the frequency domain with a separation equal to the PRF. For $B_{IF} \leq PRF$, the time waveform at the victim receiver IF output will be continuous in nature (continuous wave, CW-like), if centered on a spectral line) and its amplitude is dependent on the power in the spectral line of the UWB device, and the tuned frequency and IF selectivity characteristics of the victim receiver. For a CW-like signal, the average and peak power level are equal. For $B_{IF} > 1.7$ PRF, the time waveform at the victim receiver IF output will be pulse-like with the amplitude and pulse width being dependent on the receiver IF bandwidth.

3.5.1.1 Average (RMS) Power BWCF Transfer Properties for Non-Dithered UWB Signals

For $B_{IF} \leq$ PRF, the average (RMS) power $BWCF_A$ can be expressed as:

$$BWCF_A = 0, \quad \text{for } B_{IF} \leq PRF \text{ and } B_{Ref} < PRF \tag{3-5}$$

$$BWCF_A = 10\log(PRF/B_{Ref}), \quad \text{for } B_{IF} \leq PRF \text{ and } B_{Ref} \geq PRF \tag{3-6}$$

For B_{IF} > PRF, the average (RMS) power of the UWB signal at the receiver will vary as a 10log trend for $PRF \leq B_{IF} < 1/T$.

$$BWCF_A = 10\log_{10}(B_{IF}/PRF), \quad \text{for } PRF \leq B_{IF} < 1/T \text{ and } B_{Ref} < PRF \tag{3-7}$$

$$BWCF_A = 10\log_{10}(B_{IF}/B_{Ref}), \quad \text{for } PRF \leq B_{IF} < 1/T \text{ and } B_{Ref} \geq PRF \tag{3-8}$$

For $B_{IF} \geq 1/T$, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

3.5.1.2 Peak Power BWCF Transfer Properties for Non-Dithered UWB Signals

For $B_{IF} \leq 0.45$ PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 0, \quad \text{for } B_{IF} \leq 0.45\ PRF \text{ and } B_{Ref} < PRF \tag{3-9}$$

$$BWCF_P = 10\log(PRF/B_{Ref}), \quad \text{for } B_{IF} \leq 0.45\ PRF \text{ and } B_{Ref} \geq PRF \tag{3-10}$$

For $B_{IF} > 0.45$ PRF, the peak power of the UWB signal at the receiver will vary as a 20log bandwidth trend for $0.45\ PRF \leq B_{IF} < 1/T$.

$$BWCF_P = 20\log_{10}[B_{IF}/(0.45 \times PRF)], \quad \text{for } 0.45\ PRF \leq B_{IF} < 1/T \text{ and } B_{Ref} < PRF \tag{3-11}$$

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2 \times B_{Ref} \times PRF)], \quad \text{for } 0.45\ PRF < B_{IF} < 1/T \text{ and } B_{Ref} \geq PRF \tag{3-12}$$

For $B_{IF} \geq 1/T$, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

Figures 3-1 and 3-2 show representative BWCF curves for 0.1 MHz and 10 MHz PRF non-dithered UWB signals.

3.5.2 UWB Dithered Pulse Trains

The receiver IF output response to a time dithered UWB signal may appear noise-like or pulse-like, and depends on the ratio of the UWB signal PRF to the victim receiver IF bandwidth (B_{IF}). The degree to which the receiver output response appears noise-like depends on two factors: 1) the percentage dither of the inter-pulse period, and 2) the randomness of the dither process. The receiver BWCF transfer properties given below are based on 50 percent dithering with a random algorithm. That is, the pulse delay will vary randomly between 0 percent and 50 percent of the interpulse period with a uniform distribution.

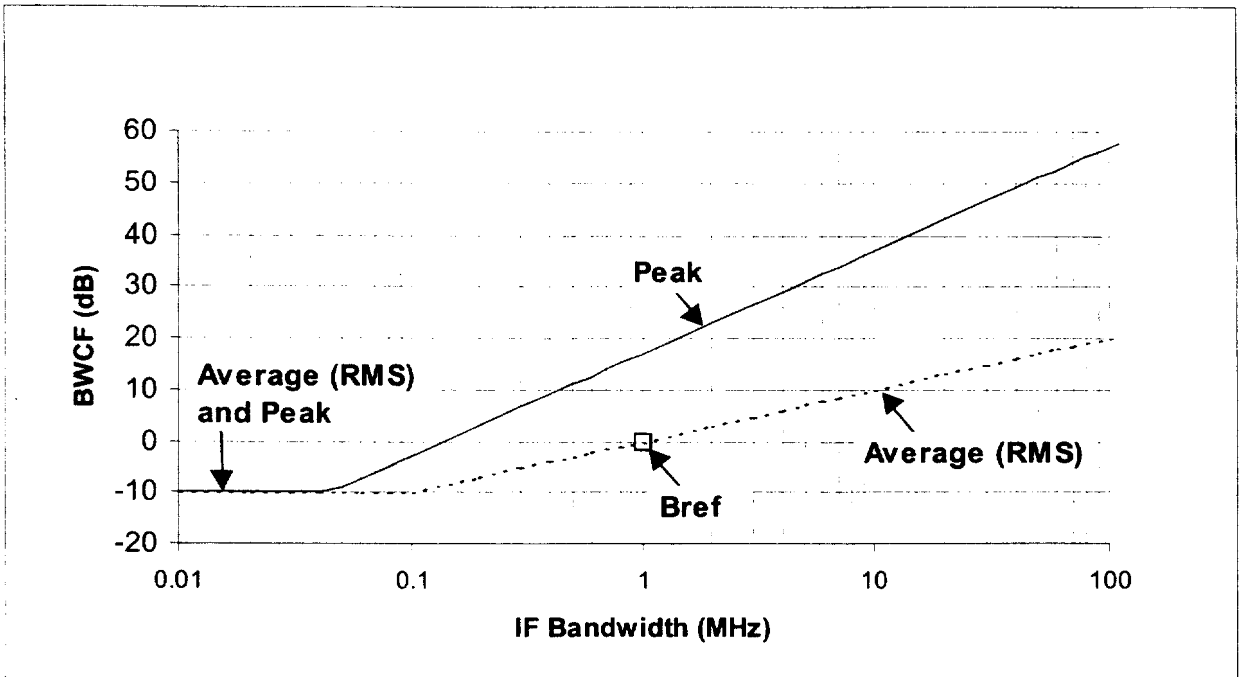

Figure 3-1. BWCF for 0.1 MHz PRF Non-dithered UWB Signal.

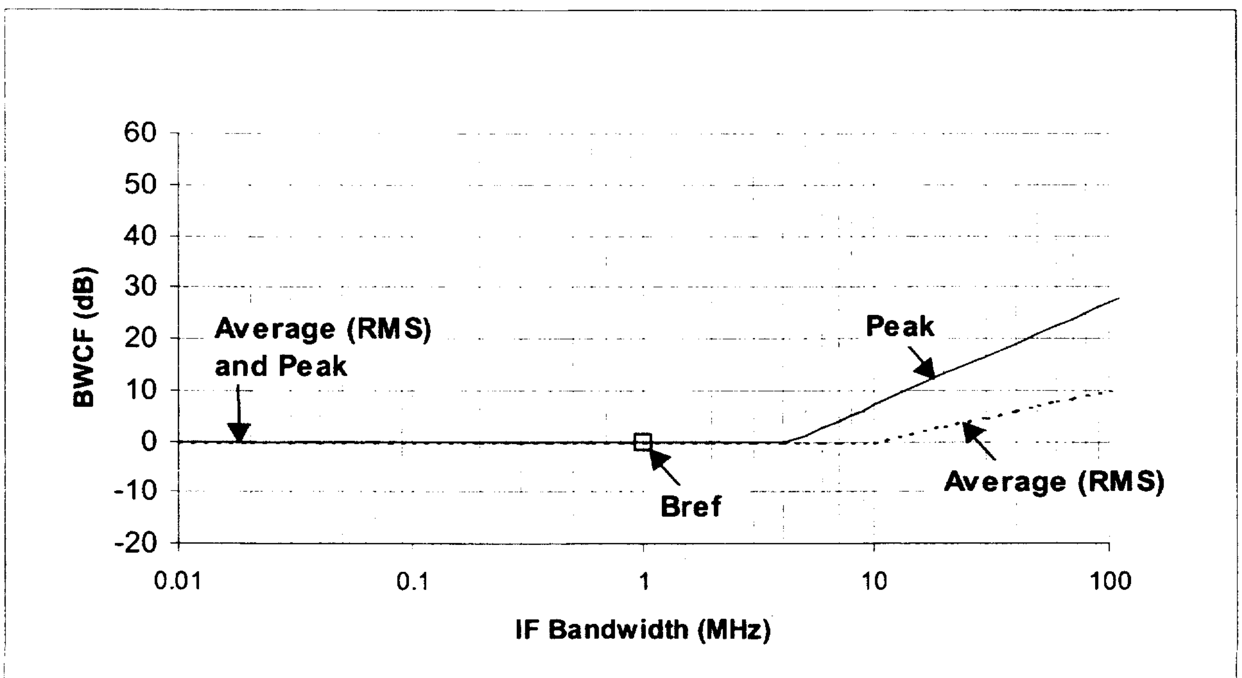

Figure 3-2. BWCF for 10 MHz PRF Non-dithered UWB Signal.

In general, for dithered UWB signals, the receiver IF output response appears noise-like for $B_{IF} \leq 0.2$ PRF and pulse-like for $B_{IF} > 1.7$ PRF. Thus, there is a transition region, $0.2 \text{ PRF} < B_{IF} < 1.7 \text{ PRF}$, where the receiver response transitions from noise-like to pulse-like. When the UWB signal appears noise-like at the receiver IF output, the average (RMS) power of the noise-like signal should be used in assessing receiver performance degradation. However, when the UWB signal appears pulse-like at the receiver IF output, either average or peak power should be used in assessing receiver performance degradation based on receiver desired signal processing. Therefore, both average and peak UWB signal receiver transfer properties for BWCF are provided below.

3.5.2.1 Average (RMS) Power BWCF Transfer Properties for Dithered UWB Signals

For $B_{IF} \leq 0.2$ PRF, the time waveform at the victim receiver IF output will be more noise-like with the amplitude being dependent on the IF bandwidth of the victim receiver. For noise-like signals at the receiver IF output, the average (RMS) power will change with a 10log bandwidth trend. As the UWB signal transitions to become pulse-like at the receiver IF output, $0.2 \text{ PRF} < B_{IF} < 1.7 \text{ PRF}$, and then becomes pulse-like, $B_{IF} \geq 1.7$ PRF, the average (RMS) power of the UWB signal will also continue to change with a 10log bandwidth trend. Therefore, for a 50 percent time dithered UWB signal, the average (RMS) power BWCF can be expressed as:

$$BWCF_A = 10\log_{10}(B_{IF}/B_{Ref}), \quad \text{for any value of } B_{IF} \text{ and } B_{Ref} \qquad (3\text{-}13)$$

For $B_{IF} \geq 1/T$, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

3.5.2.2 Peak Power BWCF Transfer Properties for Dithered UWB Signals

For $B_{IF} < 0.2$ PRF, as mentioned previously, the UWB signal time waveform at the victim receiver IF output will be noise-like and only average (RMS) power should be used to assess receiver performance degradation. Therefore, Equation 3-13 should be used; however, the receiver IF bandwidth (B_{IF}) **must** be less than 0.2 PRF of the UWB signal.

For $B_{IF} \geq 0.2$ PRF, as the signal transitions to become pulse-like it may be appropriate to use peak power of the UWB signal at the receiver IF output to assess receiver performance degradation. The peak amplitude of the UWB signal increases as a 20log bandwidth trend, and the pulse width at the receiver IF output will be approximately equal to the impulse response of the IF filter ($1/B_{IF}$). The peak power BWCF is given by:

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2\times B_{Ref}\times PRF)], \quad \text{for } 0.2 \text{ PRF} < B_{IF} < 1/T \text{ and } B_{Ref} = \text{any value} \qquad (3\text{-}14)$$

For $B_{IF} \geq 1/T$, the receiver IF output pulse width is equal to or greater than the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

Figures 3-3 and 3-4 show representative BWCF curves for 0.1 MHz and 10 MHz PRF time dithered UWB signals.

3.6 DETECTOR CORRECTION FACTOR (DCF)

A DCF is needed when the UWB signal is dithered and the receiver response at the IF output is noise-like, and the Part 15 measurement procedure requires quasi-peak detection (see TABLE 2-1, Note "a"). For noise-like responses at the receiver IF output, the receiver degradation should be based on the average (RMS) power of the noise-like signal, and not the quasi-peak level of the noise-like signal. Based on measurements, there is approximately an 8 dB difference between the quasi-peak level and the average level of a noise-like signal. Therefore, for receiver systems operating below 1000 MHz, where quasi-peak detection is required, the DCF should equal -8 dB.

3.7 GATING FACTOR (GF)

Some UWB devices turn the pulse train off for a period of time which is referred to as gating. The percentage of time the pulse train is on is referred to as the gating percent. That is. 25 percent gating means that the signal is on for one-quarter of a period of time, and off for three-quarters of the period. The average (RMS) power level of the UWB signal will depend on the period of time over which the signal is measured. For example, if the average (RMS) power level is measured over the entire gating period, the average (RMS) power level will be lower than if the average (RMS) power level is measured only during the time the pulse train is gated on. If the average (RMS) power level is measured over the gating period, this could result in a higher peak to average (RMS) power ratio if the UWB signal power level was increased to maintain a specified emission average (RMS) power limit. To correct for this increase in peak-to-average (RMS) power ratio, the following correction should be made when peak power is used in assessing performance degradation:

$$GF = 10\log_{10} GP/100 \qquad (3\text{-}15)$$

where: GP = the percentage of time the signal is transmitted (gated on)

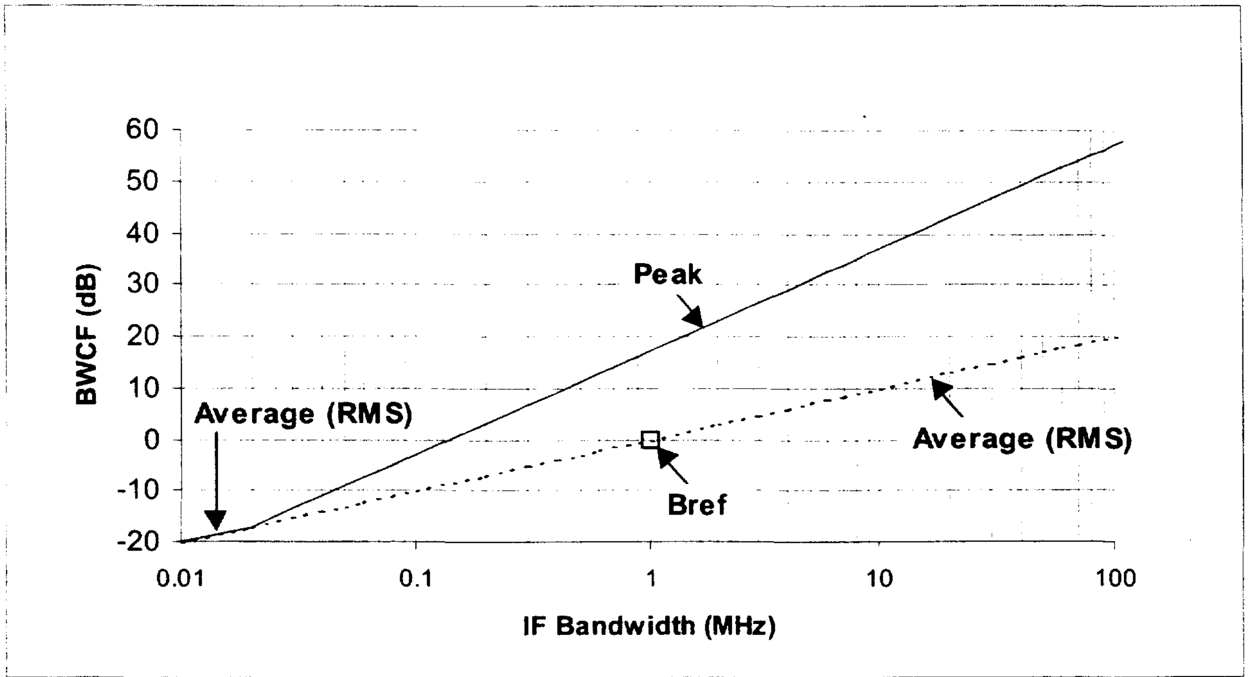

Figure 3-3. BWCF for 0.1 MHz PRF Dithered UWB Signal.

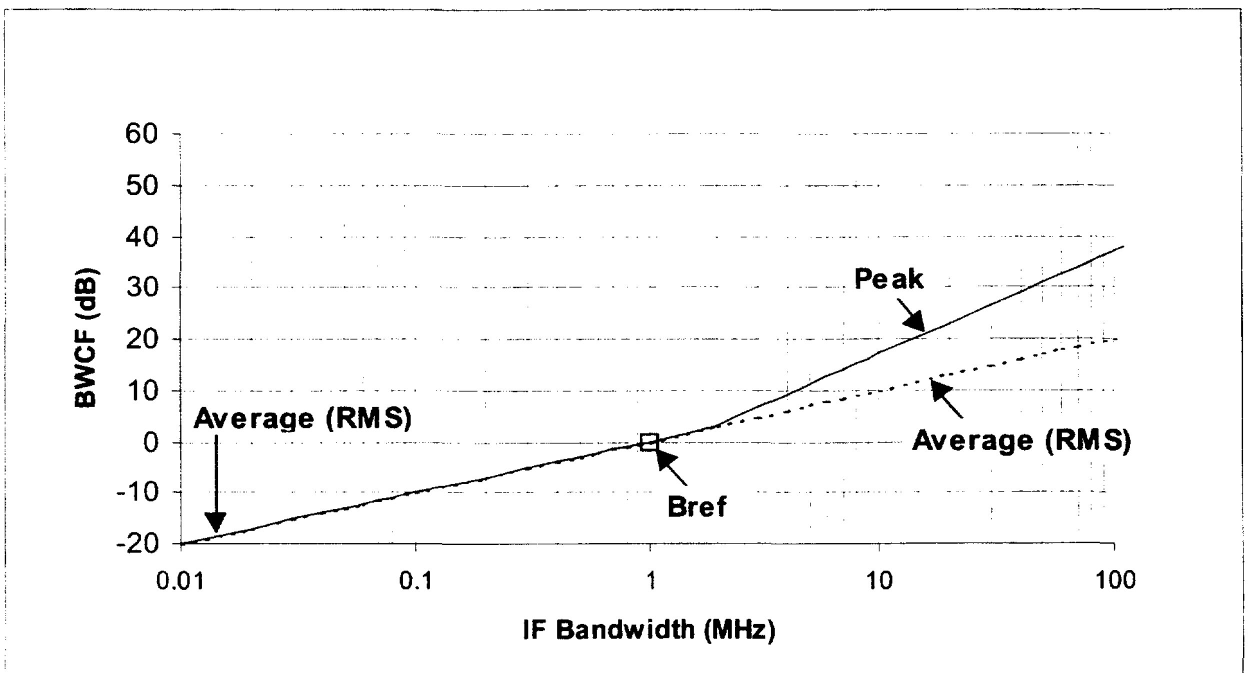

Figure 3-4. BWCF for 10 MHz Dithered UWB Signal.

3.8 SYSTEM CHARACTERISTICS

Representative system characteristics for the Federal telecommunication systems and UWB devices related to the parameters in Equations 3-1 through 3-15 were identified. The following representative UWB characteristics were chosen to conduct the EMC analysis.

PRF = Pulse repetition frequency, in pulses per second, nominal range is 1 kHz to 500 MHz.
Dither = 0% (non-dither) or 50%
Gating = 0% or 50%
Antenna type = Omni (0 dBi gain)
Antenna height = 2 and 30 meters

The Federal telecommunication system characteristics used in the EMC analysis are contained in Appendix A.

3.9 DESCRIPTION OF EMC ANALYTICAL MODEL

A series of spreadsheets were developed for each system to implement Equations 3-1 through 3-15 and the associated routines necessary to compute the propagation loss and antenna vertical off-axis gains. The ITS Irregular Terrain Model (ITM)[31] of radio propagation which is based on electromagnetic theory and on statistical[32] analysis of both terrain features and radio measurements was used to predict the median attenuation as a function of distance and the variability of the signal in time and space. The antenna patterns were coded such that the gain could be determined as a function the relative heights of the system of interest and the UWB source and the distance between them. This approach provides a more accurate estimation of the received power level from the UWB device than using the main beam gain of the receivers and freespace loss.

For the purpose of this analysis, Equation 3-1 has been modified to exclude the DCF and GF terms because, in the case of the DCF, only systems above 1 GHz are analyzed, and,in the case of the GF, all runs were made for 100 percent gating (0 dB GF for peak interference protection criteria).

This analysis procedure answers two questions by using Equation 3-16: 1) what is the maximum EIRP level allowable for a UWB device, assuming only a relatively small

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[31] National Telecommunications and Information Administration, U.S. Dept. of Commerce, A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode, NTIA Report 82-100, at 5-1 (April 1982), [hereinafter ITM Report].

[32] The time, location, and confidence levels used in the analysis were 10%, 50%, and 50% respectively and the terrain delta height factor was set to zero.

separation distance, and 2) what distance separation is necessary if a UWB device were to radiate at the proposed EIRP level of -41.3 dBm/MHz RMS? Both questions may be simultaneously answered for a given set of parameters by using the techniques used in the spreadsheet.

$$EIRP_{MAX} = + I_{MAX} - BWCF_{A/P} - G_R(\theta) + L_P + L_R \qquad (3\text{-}16)$$

In Equation 3-16, both the propagation term, L_P, and the antenna gain, $G_R(\theta)$, are functions of the distance between the transmitter and receiver, while the other terms (I_{MAX}, $BWCF_{A/P}$, and L_R) are not a function of the separation distance. Given fixed antenna heights for both the transmitter and receiver, $G_R(\theta)$ is a function of distance, and the relative difference between the antenna heights. The angle theta (θ) is computed from the $\arctan(|h_r\text{-}h_t|/\text{distance})$. Appendix A contains the antenna elevation gain patterns as a function of theta for each of the systems analyzed, and the protection criteria used in using Equations 3-2 and 3-3 to calculate the maximum permissible interference level, $I_{MAX.}$

After equations that were not functions of distance (i.e., I_{MAX}, BWCF) were solved, Equation 3-16 was solved for $EIRP_{MAX}$ at 10 meter increments in the distance range from 200 meters out to a distance of 15 kilometers more or less as the individual situation required. The distance between antennas, the off-axis angle between antennas, off-axis gain, propagation loss, and computed EIRP were then saved to a table in the sreadsheet for later reference and plotting. TABLE 3-1 is a portion of one of the tables that was saved in the analysis of the ARSR-4. The data from TABLE 3-1 is plotted in Figure 3-5. After the table was created, the PRF of the UWB device (which affects the BWCF) was changed and the calculations of $EIRP_{MAX}$ were performed again and saved in a table. The process was repeated for the PRFs of 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz saving the tables for each PRF. These calculations were again repeated for the two cases of dithered and non-dithered UWB sources which again affects the BWCF. The above processes are then repeated again for a different UWB antenna height which affects the off-axis antenna gain, thereby, influencing the $EIRP_{Max}$. The computations are reiterated for 7 PRFs, for each of two UWB cases (dithered and non-dithered) and for antenna heights of 2 and 30 meters. TABLE 3-2 is a summary of the maximum permitted EIRP (with minimal distance constraints) and distance constraints (based on the level of -41.3 dBm/MHz RMS) of 14 cases (7 PRFs dithered, and 7 PRFs non-dithered) for a UWB antenna height of 2 meters. The program computes and saves similar tables for a 30 meter antenna height.

TABLE 3-1
EIRP Calculation Results for 10 MHz PRF, non-dithered, and 2 meter UWB Antenna Height

Distance (meters)	theta (deg)	Antenna gain	ITM Propagation Loss (dB)	EIRP (dBm)
200	5.58	2.4	80.4	-42.4
210	5.32	2.7	80.8	-42.2
220	5.08	2.9	81.2	-42.1
230	4.86	3.3	81.6	-42.1
240	4.66	3.7	82.0	-42.1
250	4.47	4.1	82.3	-42.1
260	4.30	4.4	82.7	-42.1
270	4.14	4.7	83.0	-42.1
280	3.99	5.0	83.3	-42.1
290	3.86	5.6	83.6	-42.3
300	3.73	6.1	83.9	-42.6
310	3.61	6.6	84.2	-42.8
320	3.50	7.0	84.5	-42.9
330	3.39	7.9	84.8	-43.5
340	3.29	8.6	85.0	-44.0
350	3.20	9.4	85.3	-44.5
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
14970	0.07	38.04	135.52	-22.92
14980	0.07	38.04	135.53	-22.91
14990	0.07	38.04	135.55	-22.89
15000	0.07	38.04	135.56	-22.88

Ultimately, the spreadsheet determines from TABLE 3-1 and records in TABLE 3-2, the maximum permitted EIRP and minimum separation distance which are illustrated in Figure 3-5. The lowest point of the curve on the graph is the highest, or maximum allowable, EIRP from a UWB device, that does not exceed the interference criteria of the receiver of interest for a given PRF. It can be seen from Figure 3-5 that, in this instance, this level is approximately -60 dBm. The figure also shows that if the EIRP level is equal to -41.3 dBm/MHz EIRP, the UWB device must maintain a separation distance of approximately 5.5 km in order not to exceed the interference threshold of the receiver. One very important assumption in this example is the UWB antenna height. In this example, the UWB antenna height is assumed to be 2 meters and the receiving antenna is at a height of 22 meters (22 meters is the mean of actual measured antenna heights of all ARSR-4s in the United States). This factor is the reason that as the distance between the antennas is decreased to distances of less than one kilometer, the allowable EIRP increases (the line curves upwards). This is because the UWB is not in the receiving antenna's main beam. That is, the gain of the receiver is much less underneath the antenna than in front of the antenna.

Figure 3-6 graphs the same scenario as in Figure 3-5 except the UWB antenna is assumed to be at a height of 30 meters, as if it were mounted on a building or tower. As may be observed from Figure 3-6, increasing the UWB antenna height increases the antenna coupling (i.e., puts the UWB source in the main beam of the receiver antenna) and hence, increases the minimum required separation distance to approximately 15 km from 5.5 km, and conversely, reduces the maximum allowable EIRP to over -80 dBm/MHz RMS from -60 dBm/MHz RMS.

Also of note in both figures is the fact that the distance and EIRP levels are not recorded for distances of less than 200 meters. For this receiver's high gain antenna in this example, distances of less than 200 meters are not included because of uncertainty in the antenna gain characteristics.

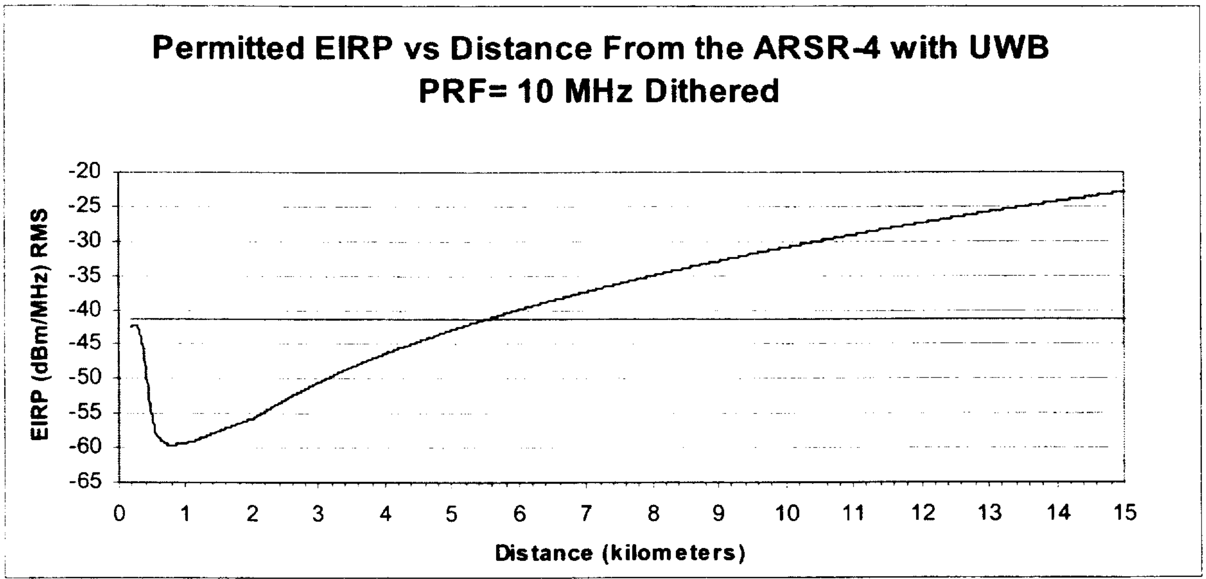

Figure 3-5. Maximum EIRP vs. Distance for 2 Meter UWB Antenna Height.

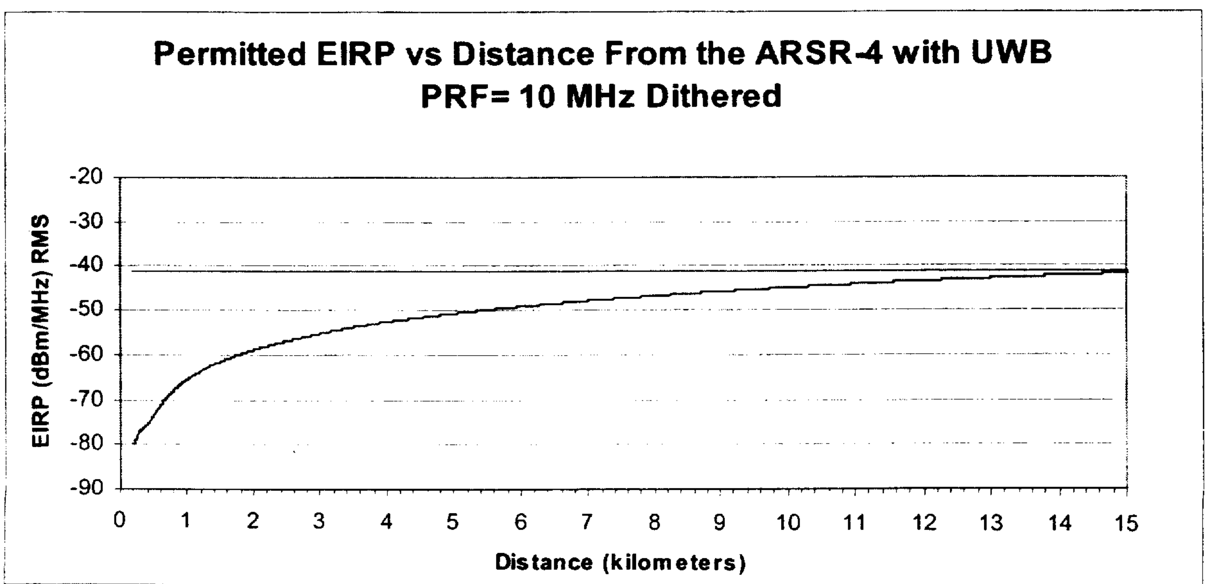

Figure 3-6. Maximum EIRP vs. Distance for UWB Antenna Height of 30 Meters.

TABLE 3-2
Two Meter UWB Antenna Height Summary

Mode	PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
Non-Dithered	0.001	-1.6	-59.6	-18.3	5.54
	0.01	-1.6	-59.6	-18.3	5.54
	0.1	-1.6	-59.6	-18.3	5.54
	1	0.0	-61.2	-19.9	6.11
	10	0.0	-61.2	-19.9	6.11
	100	0.0	-61.2	-19.9	6.11
	500	0.0	-61.2	-19.9	6.11
Dithered	0.001	-1.6	-59.6	-18.3	5.54
	0.01	-1.6	-59.6	-18.3	5.54
	0.1	-1.6	-59.6	-18.3	5.54
	1	-1.6	-59.6	-18.3	5.54
	10	-1.6	-59.6	-18.3	5.54
	100	-1.6	-59.6	-18.3	5.54
	500	-1.6	-59.6	-18.3	5.54

3.10 COMPARISON OF EMC ANALYTICAL MODEL AND MEASUREMENTS

Measurements were made on two telecommunication systems, an ARSR-4 and an ASR-8, for the purpose of assessing the adequacy of the EMC analysis procedure and the analytical model discussed in Section 3.9. A discussion of the measurements made in Oklahoma City, Oklahoma, are contained in Appendix C. Measurements were initially made with the UWB signal coupled directly into the receiver front-end to observe the receiver response to the UWB signal which were followed by radiated measurements made at several distances from the receiver. Measurements were made using a UWB PRF of 10 MHz with the signal being non-dithered and dithered. The general measurement approach was to set up the UWB signal source with a level which produced an EIRP equivalent to the Part 15 limit using the FCC measurement procedure. That is, an EIRP of -41.3 dBm/MHz log-average. For each measurement site, the increase or absence of an increase in the receiver inherent noise level caused by the UWB signal was observed at the receive IF output. That is, an (I+N)/N ratio at the receiver IF output was measured and converted to an equivalent I/N ratio. An UWB EIRP level which would not exceed the receiver I/N protection criteria was then determined.

Measurements were made at three sites on the ARSR-4. The parameters used in the analytical model are given below, and are based on the characteristics of the radar on which measurements were made and the UWB source set-up.

ARSR-4 Parameters:

Operating Frequency: 1241 MHz
IF Bandwidth: 0.69 MHz
Receiver NF: 3.6 dB
Receiver Losses: 0 dB

Antenna Gain: 41.0 dB
Antenna Tilt Angle: 2 degrees
Antenna Height: 26 meters
Protection Criteria: I/N = -10 dB, average

UWB Parameters:

PRF: 10 MHz dithered
Antenna Height: 4 meters

TABLE 3-3 shows a comparison of the analytical model results with the measured data taken on the ARSR-4 for the 10 MHz dithered UWB signal. Figure 3-7 shows the predicted and measured maximum permitted EIRP as a function of distance for the ARSR-4 for a 10 MHz dithered UWB signal. For the three measurement sites, the average difference between the predicted and measured EIRP was -1.9 dB.

Measurements were made at two sites on the ASR-8. The parameters used in the analytical model are given below, and are based on the characteristics of the radar on which measurements were made and the UWB source set-up.

ASR-8 Parameters:

Operating Frequency: 2770 MHz
IF Bandwidth: 0.9 MHz
Receiver NF: 4.0 dB
Receiver Losses: 2.0 dB

Antenna Gain: 33.5 dB
Antenna Tilt Angle: 1.5 degrees
Antenna Height: 15 meters
Protection Criteria: I/N = 10 dB, average

UWB Parameters:

PRF: 10 MHz non-dithered and dithered
Antenna Height: 4 meters

TABLE 3-3
Comparison of Measurements with Analytical Model
for ARSR-4 and 10 MHz Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	1.26	-58.0	-56.9	1.1
2	2.1	-55.2	-59.1	-3.9
3	3.1	-52.7	-55.7	-3.0

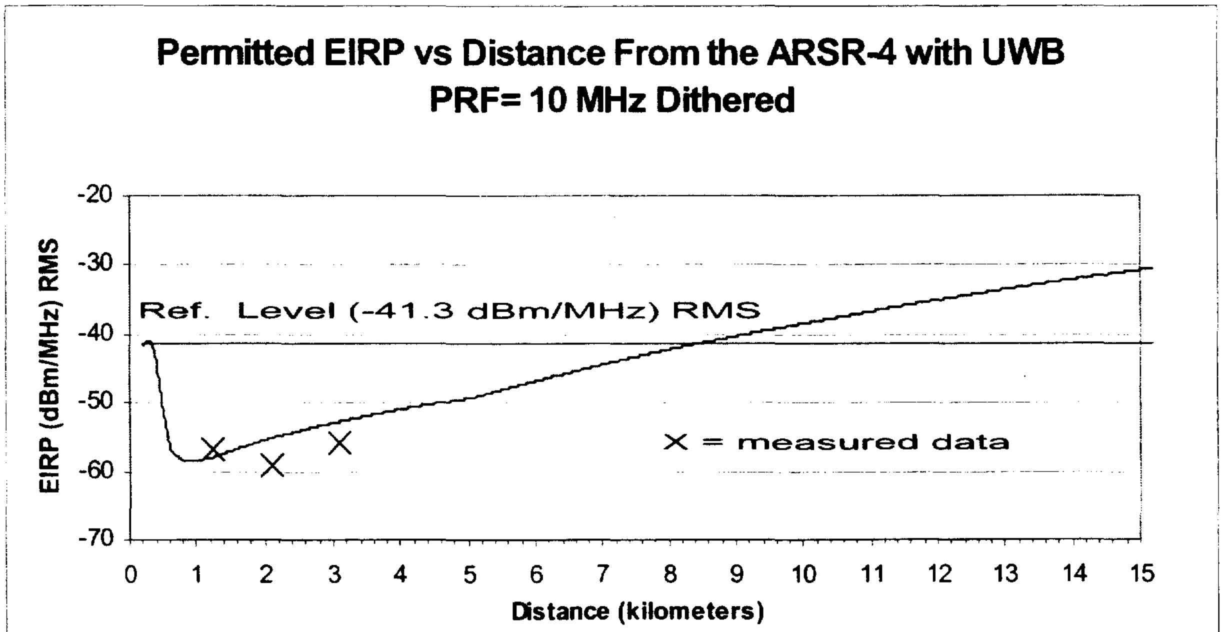

Figure 3-7. Comparison of Measured and Predicted Maximum Permitted EIRP versus Distance From ARSR-4 for 10 MHz Dithered UWB Signal

TABLE 3-4 shows a comparison of the analytical model results with the measured data taken on the ASR-8 for the 10 MHz non-dithered UWB signal. Figure 3-8 shows the predicted and measured maximum permitted EIRP as a function of distance for the ASR-8 for a 10 MHz non-dithered UWB signal. For the two measurement sites, the average difference between the predicted and measured EIRP for the 10 MHz non-dithered UWB signal was -7.0 dB.

TABLE 3-5 shows a comparison of the analytical model results with the measured data taken on the ASR-8 for the 10 MHz dithered UWB signal. Figure 3-9 shows the predicted and measured maximum permitted EIRP as a function of distance for the ASR-8 for a 10 MHz dithered UWB signal. For the two measurement sites, the average difference between the predicted an measured EIRP for the 10 MHz dithered UWB signal was -4.0 dB.

In summary, a comparison of measured maximum permitted EIRP limits with the analytical model indicates that for the ARSR-4 and ASR-8 systems, the analytical model and the measurements are within a few dB. The EIRP limits determined by measurements were generally lower. This difference may be due to several factors. For example:

1. The analytical model does not take into consideration exact terrain variations, and

2. The radar antenna elevation pattern used in the analytical model may not accurately represent the antenna gain in the direction of the UWB device.

TABLE 3-4
Comparison of Measurements and Analytical Model
For the ASR-8 and 10 MHz Non-Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	0.4	-48.0	-53.4	-5.4
2	1.4	-40.0	-48.7	-8.7

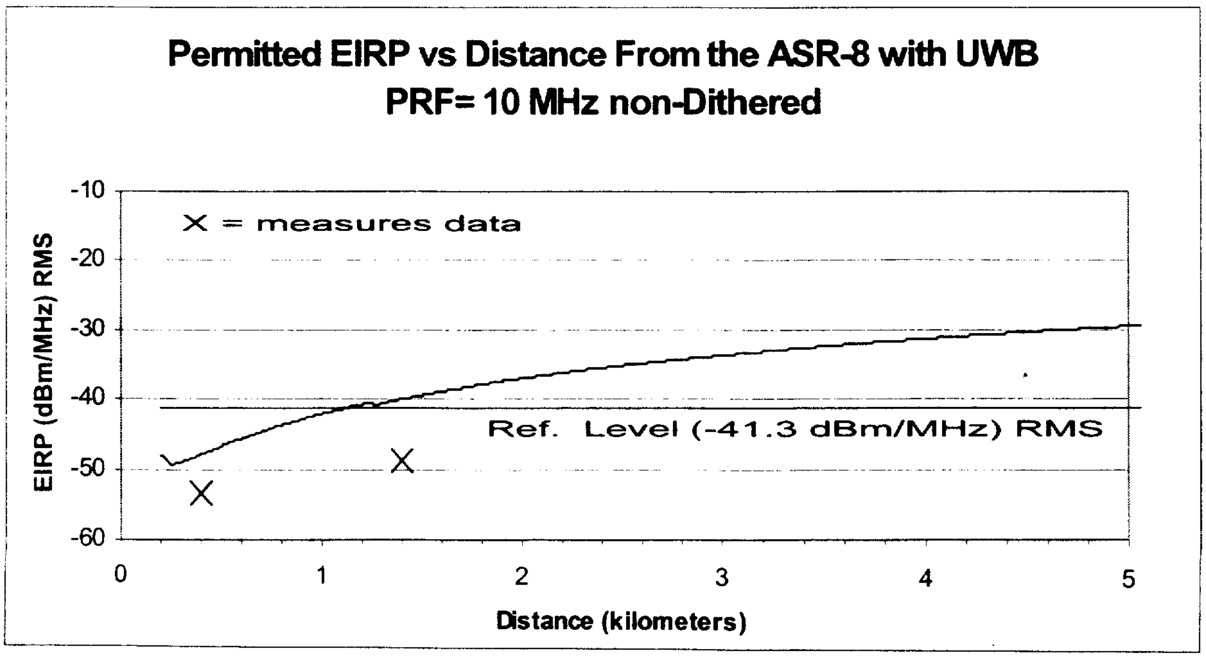

Figure 3-8. Comparison of Measured and Predicted Maximum Permitted EIRP versus Distance from ASR-8 for 10 MHz non-Dithered UWB Signal.

TABLE 3-5
Comparison of Measurements and Analytical Model
For the ASR-8 and 10 MHz Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	0.4	-47.5	-49.7	-2.2
2	1.4	-39.6	-45.4	-5.8

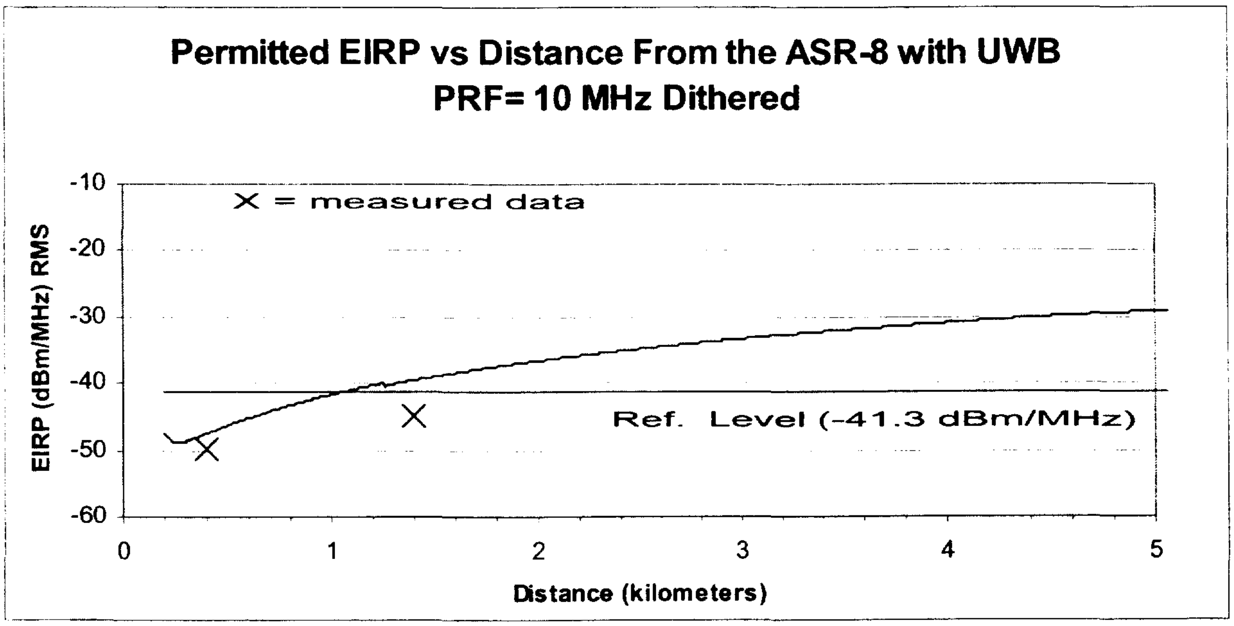

Figure 3-9. **Comparison of Measured and Predicted Maximum Permitted EIRP Versus Distance From ASR-8 for 10 MHz Measured Dithered UWB Signal**